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September 15, 1994

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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

William Caton
Acting Secretary
Federal Communications Commission
1919 M Street, NW, Room 222
Washington, DC 20054

Re: **Ex Parte Communication in PR Docket No. 93-61**

Dear Mr. Caton:

Pursuant to Section 1.1206(a)(2) of the Commission's Rules, notice is hereby given of an *ex parte* communication regarding the above-referenced proceeding. An original and one copy of this letter are being filed with the Secretary's Office.

This morning, David E. Hilliard of Wiley, Rein & Fielding, and Michael A. Lewis, Engineering Policy Advisor for Wiley, Rein & Fielding, representing Pinpoint Communications, Inc. ("Pinpoint") and Amtech Corporation ("Amtech"), met with F. Ronald Netro, Edward R. Jacobs and John J. Borkowski of the Private Radio Bureau.

We discussed the positions taken by Pinpoint and Amtech in this proceeding. We also discussed Pinpoint's and Amtech's support for a Modified NPRM Band Plan. Copies of the materials supplied during our meeting are attached.

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List A B C D E

If there are any questions regarding this matter, please contact the undersigned.

Respectfully submitted,

David E. Hilliard

David E. Hilliard
Attorney for Pinpoint Communications, Inc.
and Amtech Corporation

cc: F. Ronald Netro
John J. Borkowski
Edward R. Jacobs

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SEP 15 1994

FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

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September 15, 1994

William F. Caton
Acting Secretary
Federal Communications Commission
1919 M Street, NW
Washington DC 20554

Re: PR Docket No. 93-61
Ex parte Presentation

Dear Mr. Caton:

On several previous occasions in this proceeding, parties have filed presentations mischaracterizing the design choices of Pinpoint Communications, Inc.'s ARRAY™ automatic vehicle monitoring ("AVM") system in an effort to discredit them. Pinpoint has responded to each criticism in turn. Most recently, the Chairman of the Consumer Radio Section of the Telecommunications Industry Association, Dr. Jay E. Padgett, has filed a paper ostensibly aimed at discrediting several central aspects of the Pinpoint design.[1] Specifically, Dr. Padgett addresses some of the fundamental design tradeoffs associated with wide-area AVM systems. His conclusions are (1) that the maximum locating capacity of a wide-area AVM system depends not upon the return link bandwidth but only upon the transmitted power of the mobile units and the spatial density of the base station receivers, (2) that the integration of the locating and data messaging functions is spectrally inefficient, (3) that wideband forward links are less spectrally efficient than narrowband forward links and lead to unnecessary harmful interference problems, both received and caused.

Contrary to his stated purpose, however, Dr. Padgett analyzes several design considerations such as ranging bandwidth, capacity, power levels, and forward link

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[1] Dr. Jay E. Padgett, Wide Area Pulse-Ranging AVM/LMS: Messaging/Locating System Design Tradeoffs and Part 15 Interference, August 8, 1994 ("Padgett Paper"), submitted in PR Docket No. 93-61 as an attachment to Letter from Dr. Padgett, Chairman, Consumer Radio Section, Telecommunications Industry Association, to William F. Caton, Secretary, FCC, dated August 12, 1994.

bandwidth in isolation rather than from a *system* perspective, preventing him from making a realistic assessment of the tradeoffs in the ARRAY™ design critical to successful real- world operation. Further, to reach some of his conclusions, Dr. Padgett inaccurately characterizes the nature and intent behind the ARRAY™ system as it has been presented consistently throughout this proceeding in Pinpoint's comments, reply comments, and ex parte presentations.

Pinpoint possesses a high degree of confidence that the Commission staff have discerned the failure of Dr. Padgett to analyze the ARRAY™ design from a system perspective and the ramifications of that failure. Nevertheless, Pinpoint would like to take this opportunity to respond to some of Dr. Padgett's mistaken views and erroneous conclusions concerning the design of the ARRAY™ system, as well as his resulting inappropriate recommendations regarding Commission rules for wide-area AVM systems. Pinpoint will concentrate on the following design choices and the advantages they confer on the ARRAY™ design from a system perspective: the choice of a bandwidth of at least 8 MHz to obtain the necessary capacity and ranging accuracy, the use of a multipulse ranging approach, the integration of radiolocation and data messaging, and the use of a wideband rather than narrowband forward link. As explained more fully below, by using a wideband forward link on the same spectrum assigned to its return link, Pinpoint avoids the need for an allocation of 1.3 to 4 MHz of dedicated spectrum in addition to its return link bandwidth. Pinpoint will also discuss the high degree of compatibility of its ARRAY™ system with Part 15 devices, and contrast that with the potential of the Metricom data distribution system to cause a high degree of interference. The vast majority of Part 15 devices, including cordless phones, consumer audio and video products, wireless LANs and low-powered automatic utility meter reading systems, should be compatible with operation of the ARRAY™system. As shown herein, the compatibility problem is not Part 15 versus AVM, but Metricom's proposed use versus AVM and others in the band.

General System and Design Considerations

Pinpoint began the ARRAY™ system design process with the intent of building a radiolocation system that could be used for a wide variety of potential AVM applications at a significantly more affordable cost than had been previously possible. Based upon our understanding of spread spectrum systems and the fact that the Commission had made the 902-928 MHz band available for multilateration AVM systems on a shared basis, we chose a high-capacity design with ranging uncertainty limited by the timing variance distortion to be encountered in the severe multipath environment of urban and suburban areas. We concluded that a bandwidth preferably of 12-16 MHz, but certainly no less than 8 MHz, would support these objectives. This plan incorporated a design capable of spectrum sharing amongst a variety of users of this band, including other multilateration AVM systems. A cornerstone of our spread spectrum implementation was the use of SAW devices, since they were an effective means of implementing a low-cost, high-speed radiolocation technology. Due to the relatively short integration times available from practical devices, a "multipulse" implementation was used to increase the process gain and hence interference jamming margin.[2] Other unique characteristics of this design relative to those of other wide-area AVM systems are the integration of vehicle location and data messaging on the same mobile-to-base signal, and the use of a wideband forward link identical in signal characteristics to the mobile-to-base return link for the high- capacity, outbound control and messaging functions, since such a design would not require any additional "dedicated spectrum" and is inherently time-sharable.

After considerable deliberation and a weighing of all tradeoffs associated with the differing prospective system designs, Pinpoint settled on these design elements as more advantageous for the types of AVM services that Pinpoint intended to offer. Had Pinpoint's business objectives been different or had the operating environment of the 902- 928 MHz band been other than it was and is, Pinpoint may have made different design decisions. But because Pinpoint planned to provide high-capacity vehicle location that could support IVHS initiatives such as advanced traffic management and control and to do it in a shared spectrum environment (as dictated by the Commission's current rules), Pinpoint made the choices it did.

Use of a Bandwidth of at Least 8 MHz

Pinpoint based its selection of bandwidth upon two principal factors: first, the bandwidth had to be large enough to satisfactorily overcome problems in ranging and high-speed data communication caused by the severe multipath distortion found in urban and suburban environments, so as to ensure adequate ranging accuracy and data management in these environments. Second, the bandwidth had to be large enough (in combination with the mobile transmit power levels and base station density) to ensure sufficient capacity in a shared spectrum environment to support the AVM applications that Pinpoint intended its ARRAY™ system would serve. In both cases, Pinpoint has proposed the use of a 12-16 MHz bandwidth which

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[2] "Multipulse" in this context mean that a vehicle is located through the use of multiple, relatively short pulses that are integrated and averaged, rather than a single relatively long pulse from mobile-to-base.

simultaneously optimizes a number of Pinpoint's design and spectrum utilization objectives. Pinpoint has consequently focused its efforts in PR Docket No. 93-61 to date on obtaining access to this amount of spectrum on a shared basis with other wide-area AVM systems as well as local-area (AVI) systems. In light of the developments in this proceeding, Pinpoint will discuss here the performance tradeoffs of using only 8 MHz.[3] Reducing the bandwidth compromises the system's ability to minimize the effects of multipath induced timing uncertainty, and hence ranging accuracy, as well as capacity. Reducing the bandwidth significantly below 8 MHz would either degrade the system's ranging accuracy to unacceptable levels or undermine system capacity so as to put into doubt the economic acceptability of using spectrum on a shared basis. The effect of such a constraint would be to deprive the public of a choice among significantly different competitive AVM technologies.

In understanding the effects of bandwidth selection on the ability to overcome problems associated with multipath, it is critical to understand the distinction and relationship between "timing uncertainty" and "ranging accuracy" and the factors that affect each of them. Timing uncertainty is the measure of uncertainty in a time-of-arrival estimate.[4] "Ranging accuracy" is a measure of the correctness of the location provided by an AVM system for a vehicle.[5]

A number of submissions in Docket 93-61 fail to keep clear these distinctions and relationships, which are discussed in greater detail below. In essence, the problem occurs either when one of several factors affecting timing uncertainty is equated with timing uncertainty or when timing uncertainty is equated with ranging accuracy. The factor which has often been the focus of these discussions, defined as "noise-induced-timing-uncertainty" below, is by no means the dominant factor affecting timing uncertainty in urban and suburban environments. Indeed, at the bandwidths of interest, above 1 MHz, this factor is extremely small compared to the effects on timing uncertainty induced by multipath in these environments. Unlike noise-induced-timing-uncertainty, adequately addressing multipath induced timing uncertainty is extremely dependent on bandwidth.

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[3] Reducing the bandwidth available for an AVM system can adversely affect the throughput, resolution and accuracy of the system. Some of these effects can be compensated for by using higher mobile power and greater base station density, but the overall effect is to increase significantly both the infrastructure and operating costs of the network.

[4] Timing uncertainty is sometimes called "timing resolution" by others.

[5] Ranging accuracy is sometimes referred to as "position uncertainty" or "range uncertainty."

To appreciate the confusion, one must first recognize that ranging accuracy of a system is dependent on several factors, of which the timing uncertainty is only one, although perhaps the most significant. Others include uncertainties in the base station receiver locations, geometric relationships at the point of solution, and the uncertainty between the time-measuring standards used at different base stations.

Timing uncertainty itself is a function of several factors: one is induced by either thermal noise or moderate interference from jammers and affects the carrier-to-noise ratio available to the arrival time estimator (and its relationship to the other system factors is well summarized in the Cramer-Rao bound quoted by Dr. Padgett). For the purposes of this discussion, let us call such contributions to timing uncertainty "noise-induced-timing-uncertainty". Another source of uncertainty is induced by the multipath environment, as Dr. Padgett also acknowledges, which we will call "multipath induced timing uncertainty."

As discussed in the *Padgett Paper*, in the absence of multipath, it is quite easy to obtain timing uncertainties caused by thermal noise or jammer interference on the order of tens of nanoseconds (i.e., tens of feet) with bandwidths of about 4 MHz. As he observes, doubling or quadrupling the bandwidth under these idealized non-multipath conditions leads to small absolute improvements in the timing uncertainties.

However, focusing on a non-multipath scenario is misleading and does not lead to useful conclusions. Use of wide-area AVM systems will be most intense in urban and suburban environments. In these conditions, the effects of multipath can introduce timing uncertainties as large as a few microseconds, which can translate into ranging errors of greater than a thousand feet per microsecond[6], depending on geometric factors.

Dr. Padgett correctly notes that urban multipath induced timing uncertainties far outweigh typical noise-induced-timing-uncertainties, but only after he has isolated the effects of noise-induced-timing-uncertainty and concluded therefrom that bandwidths greater than 4 MHz will not lead to appreciable improvements in the ability to overcome such uncertainties. The reader may thus be confused that any increases in bandwidth in excess of 4 MHz will not lead to significant improvements in the ability to overcome overall timing uncertainty. Precisely because noise-induced-timing-uncertainty is small relative to multipath induced timing uncertainty in the urban and suburban environment, the relationship between noise-induced-timing-uncertainty and bandwidth is largely irrelevant under realistic operating conditions.

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[6] Tens of nanoseconds equates to tens of feet.

Rather, the practical reality is that the timing uncertainty reduction and related ranging accuracy benefit obtained from additional bandwidth is very significant. This is because the ability to ameliorate timing uncertainties, and thus ranging accuracy, is not dominated by reduction of noise-induced-timing-uncertainty but instead by the reduction of multipath induced timing uncertainties. Ironically, Dr. Padgett's own Figure 1 demonstrates this point well.[7]

As noted earlier, multipath induced timing uncertainties in the urban and suburban environments can easily degrade the ranging accuracy of any system from several hundred to over a thousand feet. In such real-world operating conditions, increased bandwidth is very effective in improving overall timing uncertainty and thus ranging accuracy, as Dr. Padgett's figure demonstrates, far more so than the decrease in timing uncertainty due to improved signal-to-noise ratios, as implied by the Cramer-Rao bound. The wider bandwidth allows proportionally better separation (i.e., resolution) of the individual multipath echo pulses and gives the timing estimator

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[7] *See Padgett Paper*, at 9, Figure 1. While Dr. Padgett's figure is illustrative of the benefits of increased bandwidth in improving ranging accuracy, it is also misleading in three respects. First, the upper set of curves are mislabeled as "multipath-related error bounds per Pinpoint." The curves should rather be labeled "multipath echo pulse separating ability" and the Y axis should simply read "feet". "Multipath echo pulse separating ability" is the ability to separate individual multipath echoes and is one factor, albeit an important one, in determining the degree to which a system can overcome multipath induced timing uncertainty. These curves do not necessarily define the lower bound of that ability. Rather, when all other factors related to multipath induced timing uncertainty are accounted for, they will define a curve that is essentially the same shape as Dr. Padgett's upper curves in Figure 1., but the curves will be shifted materially down towards the X axis.

Dr. Padgett's label suggests that these upper curves represent some attribute of the ARRAY system, whereas they do not. Instead, they are merely his derivation of the range of multipath echo separating abilities of an AVM systems as a function of bandwidth based upon a Pinpoint reference which he cites.

Second, and in a similar vein, the "Teletrac" curves should be relabeled as "RMS noise induced timing uncertainty in the absence of multipath." These curves, too, are not indicative of any individual system's ranging accuracy. What these graphs indicate quite clearly is the dominance of multipath induced uncertainties in overall timing uncertainty in relation to noise-induced timing uncertainty.

As explained above, the upper curves demonstrate the ability of AVM systems more effectively to separate individual multipath echoes with increases in bandwidth on scales that are relevant to urban vehicle location, where parallel streets are often separated by only three or four hundred feet. While there is not a one-to-one relationship between multipath separation capability and the resultant multipath induced position uncertainty, separation capability is a significant factor in the overall ranging accuracy of an AVM system and shows how that accuracy is related to bandwidth.

more of the environmentally-induced information, such as earliest-arrival versus largest-arrival and an estimate of the spread in arriving echoes, both of which are important parameters in improving the quality of the arrival-time estimates.[8]

Wider bandwidth not only allows for significantly improved ranging accuracy in actual urban and suburban operating environments, it provides for significant increases in vehicle location capacity as well, depending upon the totality of tradeoffs in a system design. From relationships like the Cramer-Rao bound, it can be seen that for a constant c/n ratio, the required pulse duration varies inversely as the bandwidth squared.[9] Pulse duration is a significant, although not the only, factor affecting the system's location capacity. Others include the maximum signal propagation times, possible control message and response message durations, network backhaul message latency and multilateration processing capacity. For location pulses that are of long duration (i.e. tens of milliseconds), in relation to signal propagation and other delays, the location capacity varies approximately inversely proportionally to the pulse duration. Therefore, under such conditions, throughput capacity would increase approximately as bandwidth squared, for a constant c/n ratio.

However, as Dr. Padgett observes, when the system is thermal noise or broadband interference limited, maintaining the c/n ratio while increasing location capacity requires increasing the mobile power in proportion to the bandwidth or increasing the base station density (thereby reducing the propagation loss appropriately), or both. Dr. Padgett appears to assert that bandwidth is irrelevant to capacity, i.e., that mobile power and base station density alone may be chosen as needed to yield the required throughput. From the above discussion, it is clear that this is simply not the case, because the Cramer-Rao bound must also be met (for adequate timing uncertainties and location rate). Additionally, the bandwidth must be

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[8] Dr. Padgett also points out that multipath induced timing uncertainty appears as a bias term if multiple measurements are made within the coherence time of the channel to reduce the ranging error. *Padgett Paper* at 9-10. While this is true, Dr. Padgett does not consider spatial redundancy as a methodology to improve overall ranging accuracy. At a minimum, an AVM system is designed for at least four base stations to receive the ranging pulses. Pinpoint anticipates, however, that its system design will generally have six or more base stations to receive any given location pulse due to the margin needed to overcome the shadow fading effect that Dr. Padgett observes. The redundancy of information in these extra measurements permits the location determination algorithm to improve the ranging accuracy by effectively averaging out multipath-induced timing uncertainties. The "processing gain" a location determination algorithm offers by using this redundancy is an important parameter in Pinpoint's evaluation of candidate algorithms.

[9] Id. at 5, equation (2).

sufficient for multipath-echo pulse separation, and both of these requirements are very bandwidth dependent. Therefore, when the system is thermal noise or broadband interference limited, increasing capacity (by shortening the duration of location pulse) at constant c/n ratio, is not obtained by merely increasing base station mobile power and density, but by increasing the bandwidth simultaneously.[10] Thus, reality for a system designer is quite different from Dr. Padgett's assertion that the *increase in capacity is solely a function of transmitter power and base station density.*

Use of a Multipulse Approach and Integration of Vehicle Location and Data

Pinpoint chose a multipulse approach for two reasons. First, Pinpoint desired to use SAW technology for the correlation function. SAW technology is fast and relatively inexpensive for the degree of signal processing it performs. Second, a single SAW integration period could not produce enough processing gain, and hence jamming margin, to compensate for the relatively high levels of interference that are and will be present in the 902-928 MHz band. In contrast, the averaging of multiple pulses provides adequate improvements in processing gain and to ranging accuracy at much lower power levels, while opening the opportunity for simultaneous data transmission.[11] Other approaches, for example increased mobile power or base

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[10] Pinpoint notes here that its claim that capacity could increase as the cube of the bandwidth was made *in the context of a single, or dominant, narrowband interferer.* Pinpoint Comments, June 23, 1993, Exhibit A at 10. Pinpoint did not say that throughput varied as the cube when the dominant interference was broadband co-channel interference as implied by Dr. Padgett.

[11] It should be noted here that on page 15 of the Padgett Paper, Dr. Padgett quotes that processing gain is often defined as the ratio of bandwidth to bit rate, implying that there may well be other definitions. In the case of the Pinpoint system's receiver implementation, his adopted definition is not the appropriate one, since it fits when only (one) bit per symbol is encoded into the ranging pulse. At other encoding rates, (i.e. more bits per symbol) the definition leads to incorrectly low estimates of processing gain. A more appropriate definition would be the ratio of bandwidth to symbol rate. Therefore, Dr. Padgett's conclusions about Pinpoint's jamming margins are seriously underestimated.

Furthermore, his discussion about there being little increase in processing gain by averaging only applies to a particular receiver architecture, which is not the architecture of the Pinpoint receiver. *See id.* at 10. Dr. Padgett appears to assume that time of arrival determination are made when the pulse comes out of the SAW device. Pinpoint, however,

(continued...)

station density, are considerably more expensive. Pinpoint's choice of mobile power and base station density was to accomplish the required throughput at an acceptable tradeoff between system infrastructure and mobile equipment costs, while achieving acceptable operating characteristics in the high-level interference environment of the shared band.

Once ranging function requirements were met through the use of multiple pulses, Pinpoint turned to the messaging and control functions needed for the AVM applications to be served by the ARRAY™ system. Pinpoint concluded that with proper event management, the same pulses that were being used for the vehicle location function could be used to carry the necessary messaging data without significantly affecting the ranging function. Thus, Pinpoint determined to integrate the radiolocation and messaging functions on the same signal.

In sharp contrast with the ranging function, however, the mobiles need not communicate with all of the base stations required for vehicle location to allow the data function to be successful, as Dr. Padgett suggests.[12] Rather only one base station need successfully identify the mobile generating the data on the timing pulse in order for the data function to be successful. For radiolocation to be successful, at least four base stations must receive the timing pulse. Therefore, it is conceivable that data messaging will be successful in instances where the vehicle location function is not. (Timing estimates and message data are sorted and coordinated at the network control center.) Of course, Pinpoint sought to avoid such an occurrence wherever possible. Consequently, the processing gain of the ARRAY™ system for vehicle location is significantly higher than the processing gain for data. Accordingly, individual receive sites are more likely to receive usable time estimates than receive valid data. System wide, however, both the vehicle location and data messaging functions are likely to have a high degree of success.

In addition, the integration of these functions does not require Pinpoint to utilize other spectrum outside that necessary for vehicle location (8 MHz or more) to accommodate the need for data messaging. Indeed, as will be shown below, if narrowband data channels were used to replace the AVM-related control and messaging capabilities of Pinpoint's current integrated system, an additional 1.3 to 3.4 MHz would be needed.

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[11](...continued)
sums the pulses out of the SAW device and then makes an estimate of the time of arrival. Consequently, his critique of Hatfield Associates estimates of the processing gain and jamming margins misses the mark. *See id.* at 16.

[12] *See Padgett Paper* at 13.

Use of a Wideband Forward Link

A wideband forward link using the same frequencies as the return link was chosen, not for the performance of ranging, but for a number of other reasons necessary for Pinpoint to design its system to perform its intended functions. A wideband forward link enables Pinpoint to concentrate its outbound link capacity in a given geographical area within a market as traffic conditions, often unpredictably, dictate. Moreover, such a design is spectrum efficient as it avoids the need for dedicated spectrum in addition to an allocation required for sufficiently accurate mobile-to-base ranging location pulses. Concomitantly, the wideband forward link, as implemented by Pinpoint, is inherently conducive to time sharing among multiple wideband systems, and to the coexistence of a wide variety of users in the 902-928 MHz band.

1. The Benefits of a Wideband Forward Link

As explained above, the choice of bandwidth for the return link is dictated largely by the need to overcome multipath distortion and achieve a satisfactory ranging accuracy, as well as the desired system capacity. Once that bandwidth is determined, choosing a wideband forward link that operates on the same frequencies does not require any additional spectrum to be allocated to the AVM system. The use of dedicated narrowband frequencies does. Thus, users seeking to avoid causing interference to the AVM system will have to avoid fewer frequencies with a system using a wideband forward link on the same frequencies as its return link than a system using a similarly sized forward link operating on separate dedicated spectrum.

The use of a wideband forward link is also conducive to effective spectrum (time) sharing because of the relatively short duration associated with each radiolocation/message delivery transaction. All systems sharing an 8 MHz or wider sub- band could easily confine their entire spectrum needs for both forward and return links within that same sub-band. If only the return link were shared, then each additional sharing system would require its own (dedicated) forward link spectrum. This is amply illustrated, in principle, by the Teletrac January 24, 1994, ex parte band plan proposal, in which each of two return link sharers would receive 1.75 MHz of dedicated spectrum. Presumably, a third system might also require its own 1.75 MHz of spectrum in order to share the 6.5 MHz return link, and so forth for each additional system.

In actuality, for high capacity AVM systems such as the ARRAY™ system, the spectrum requirements situation is even worse if a wideband forward link is not used. For the type of high-capacity applications Pinpoint envisions, the demand for vehicle location will be anything but constant and will frequently change in a highly unpredictable manner, both temporally and geographically, due to external circumstances and as a result of user requirements. The demand for location information depends on the time of day, geographic location, weather, incident occurrence, and commercial and recreational activity level, among other factors. Therefore, the "instantaneous" demand for location information in a given geographic area will vary dramatically throughout the day and from day to day.

The entire Pinpoint wideband link can be focused to one geographic area if demand requires it. For example: after a large event at a stadium such as a football game or the occurrence of a traffic accident, the service requirements in a small geographic area may be very high for a brief period. The current system easily supports the needs of this type situation and would do so automatically as required.

Conceivably, as Dr. Padgett suggests, a separate "narrowband" forward link system could be designed to support Pinpoint's high capacity operations provided it could handle substantial peak to average load variations. For a narrowband forward link system to be adequate, it must have a localized throughput relatively equivalent to that of a wideband forward link system as well as being able to support whatever uses require access to the system on a real-time basis. Because of the highly unpredictable nature of vehicle location demand in a market, a narrowband system will have to have adequate spectrum to permit the system to meet this very high localized demand at each point in the system. As a result, the overall system throughput of a narrowband system will be greater than that of a "comparable" wideband forward link system, but it is unlikely that any great advantage would be derived from that capacity. In contrast, the localized throughput would be approximately the same as a wideband system. This approach appears to be significantly less spectrally efficient because it requires use of an inordinate amount of dedicated spectrum for forward links.

2. The Inadequacy of a Narrowband Forward Link System for High-Capacity AVM

There are two basic architectural solutions that might be pursued for a narrowband forward link: a simulcast paging system and a channelized cellular approach. Each will encounter significant difficulties supporting peak-to-average load variations.

Consider a simulcast paging approach that uses a 25 kHz bandwidth to transmit 2500 bps of user data. This translates into about 35 paging polls per second[13], which incidentally is very close to the Airtouch Teletrac capacity and suggests why a single channel narrowband simulcast paging system might be a good solution for their system. In order to support Pinpoint's ARRAY™system capacity of 1500 locations/second, by comparison, more than 43 such channels would be needed, representing a total bandwidth of 1.075 MHz.

Unfortunately, this is not an adequate solution for Pinpoint because it creates a bottleneck in the system. Because it would be cost prohibitive to have the mobile listen to all 43 channels simultaneously, each mobile must be assigned a channel on which to listen.[14] Thousands of mobile units will be assigned to each channel. In a short time frame, the network may receive requests to locate and communicate with a sufficient number of vehicles assigned to a particular channel so as to overwhelm the capacity of the channel. Additionally, the network can only be fully loaded if every paging channel is being fully consumed. The random fluctuations in requests will ensure that a system very rarely, if ever, is fully loaded. Therefore considerably more than 43 channels and more bandwidth than 1.075 MHz will be required in order to provide the flexibility and capability needed to fully utilize the network vehicle location capacity. The simulcast paging architecture approach works well for a system like Airtouch Teletrac with low vehicle location capacity, but it is a poor solution for the high capacity IVHS applications, such as those Pinpoint intends to serve.

If a narrowband forward link is going to be used, a better approach for a high capacity system may be a channelized cellular system, although it, too, will present capacity problems absent large amounts of spectrum. The channelized cellular architecture is similar to the signal channeling of the cellular telephone network. Each cell has a high speed data channel that through coding and interleaving provides a reliable link between the base station and the mobile radio. Each cell base station transmits at one frequency and the frequencies are reused after seven cells. The

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[13] The number of bits per page is assumed to be 64. Allocating 10 % of the time for resynchronizing the channel and other overhead activities will produce an effective paging rate of 35 pages/second.

[14] Such a high capacity simulcast approach would also require a huge paging infrastructure of sites with 43 transmitters per site and the sites laid out in a pattern that would assure coverage of about 10 miles from each site. A system of this kind would have sites comparable in expense ($500,000 or more each) and complexity to the entire paging infrastructure in a major market. In contrast, a Pinpoint ARRAY base station will cost $10,000 to $15,000 and occupy about four square feet of floor space.

mobile radio listens to the strongest of the seven channels, each of which transmits the same message to the mobile. Therefore, all communications to that mobile must be transmitted over the area of location uncertainty for that vehicle, which may be the entire market depending on the update rate for that mobile, and at a minimum is likely to be several cells. Each base station would thus transmit the same message to the mobile in the area of uncertainty. Only when a mobile is known to be within a given cell could the message be sent over a single base station. This basic architecture provides the means for comparison to Pinpoint's wideband forward link.

As explained below, in order to provide truly comparable capability and flexibility to that of Pinpoint's wideband forward link approach, a narrowband system using the channelized cellular architecture would need approximately 1.3 MHz of bandwidth for the location-polling function alone and approximately 3.4 MHz for a combined location and data messaging system, such as that contemplated by Pinpoint. The required bandwidth needed for such a system is derived below to match the randomly-addressed-vehicle location capability of Pinpoint AVM system -- 1500 vehicle locations per second.

a. Vehicle location only.

The current Pinpoint system needs about 6 bytes of data per location poll.[15] For 1500 location fixes per second, the total throughput required is 72 kbps.[16] Because a narrowband forward link would not be integrated (i.e. synchronous) with the return link, as would be the wideband forward link, the narrowband system must also send to the mobile the time at which it should respond, which requires approximately 2 bytes of information. Therefore, a location poll in a narrowband system requires a total of about 8 bytes, and a throughput of 96 kbps for 1500 vehicle locations, 33 percent more than with a wideband forward link.

A typical narrowband FM system needs 2 Hz/bit to transfer data at a 10-6 BER. (The channel rate can be less than 1 Hz/bit but coding and interleaving reduces

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[15] This message length accommodates mobile address, operational code, a check-sum, and a status byte.

[16] Pinpoint's current system, when dedicated to vehicle location alone can support 1500 randomly addressed position fixes per second and upwards of 3000 group addressed position fixes per second. Coincidental with the vehicle location function, the ARRAY system can also support status messaging without any appreciable loss in location capacity. If additional messaging is required, there will be some corresponding loss in location (plus status messaging) capacity.

the information rate to 2 Hz/bit.) Thus, the total bandwidth in any given cell is 192 kHz for 1500 location/second. If a seven cell reuse pattern is in use, then enough spectrum must be allocated to give each cell this capacity, or a total of 1.344 MHz.[17]

b. Vehicle location and data messaging.

Pinpoint's current system can support varying mixes of high capacity vehicle location and data messaging related to the vehicles being located.[18] For example, ARRAY™ can determine the location of 500 vehicles/second while simultaneously delivering 2400 bit messages to 85 of them.[19] This is an equivalent forward link rate of approximately 240 kbps.[20] To achieve this rate within cells using typical narrowband FM technology, a bandwidth of 480 kHz would be required (at 2 Hz/bit). Using a seven cell reuse pattern typical of cellular phone system means the total required bandwidth is 3.36 MHz.

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[17] Dr. Padgett postulates that using a wideband forward link deprives the return link of airtime that could be used for additional vehicle locations. Theoretically, removing the forward links would allow Pinpoint to increase its return link capacity by 50 percent, supporting up to 2250 randomly addressed vehicle locations per second. If that is the case, then any estimates for spectrum requirements for a separate narrowband forward link system must be increased by 50 percent as well, i.e. from 1.344 to 2 MHz in a vehicle location only scenario.

It is also noted that decreasing the size of the cells will not increase the overall effective location throughput as might be supposed. Any anticipated throughput gains from smaller cell size will be offset by increased uncertainty about the cell in which a vehicle is likely to be found, requiring base stations in an increasing number of cells to send out polling signals.

[18] Much of Pinpoint's capacity, of course, would be used to support the position fixing function, and the spread of the data over the vehicles being located would be very "lumpy" as many vehicles would not utilize the data messaging capability on any given location and others would use it to varying degrees at various times.

[19] When delivering the 2400 bit messages, the base station will also transmit approximately 150 additional bits for overhead associated with message delivery and the location poll.

[20] ((64 bits/location poll) x (415 location polls)) + ((2550 bits/message) x (85 messages) = 243,310 bits.

* * *

At bottom, Dr. Padgett's misunderstanding of the advantage of the wideband link is revealed in that he does not provide for any increase over average demand when suggesting that only narrowband forward links be permitted. Nor does he account for the fact that there will be tens or hundreds of thousands of equipped mobiles on the roads in a metro market simultaneously. He postulates a system that could support 1500 vehicle locations per second only if the location requirements are evenly spread among all base stations and distributed conveniently among the equipped vehicles. AVM systems will rarely if ever see such a situation happen in practice. The pool of active mobiles is also likely to be in constant flux. Rather, the load at each base station will vary dramatically over time frames as short as seconds. Unless a large amount of spectrum was made available for narrowband forward links, Dr. Padgett's system would quickly fill the narrowband forward links available in a localized area (in a cellular approach) or for a certain group of mobiles (in a simulcast approach) and therefore would have an effective local capacity significantly less than 1500 locations per second.

Thus, Dr. Padgett's suggestion that a separate narrowband system be used for the forward links in a high capacity system such as ARRAY™ would require the dedication of considerable spectrum in addition to that required by the return link in order to ensure adequate ranging accuracy. In contrast, Pinpoint's use of a wideband forward link requires no additional spectrum assignment to the wide-area AVM system other than that independently required for the return link. Accordingly, the Pinpoint system is overall the more spectrum efficient approach and more conducive to use of the 902-928 MHz band by a multiplicity of users.

Wideband Forward Links Are by no Means the Greatest Potential Source of Interference in the 902-928 MHz Band

In an abrupt transformation of strategy within the Part 15 industry, the proponents of unlicensed devices are now suggesting that wide-area AVM systems will cause them considerable interference. Ironically, however, there are likely to be a few types of Part 15 devices rather than AVM systems that will create the most interference for other users of the 902-928 MHz band including Part 15 and wide-area AVM.

The appropriate propagation environment to assume for a realistic interference analysis is a suburban or urban environment in which AVM systems are likely to operate.[21] Under this assumption, the analysis submitted by Dr. Padgett at p. 34 of his recent paper indicates that Pinpoint's wideband forward links would raise the noise floor above -95 dBm in a 100 kHz bandwidth for more than 20 miles at 30 ft above the ground using a 5 kW ERP. As Pinpoint has noted on several previous locations, its system is designed to operate under 500 W ERP. Pinpoint originally proposed the 5000 watt power limit as a means for maintaining system reliability if the noise levels in the band were to increase considerably above current levels. As Pinpoint has noted however, use of more closely spaced base stations can permit an AVM system to "hear" its mobiles even in the presence of added noise thereby making long term operation below 500 watts ERP feasible. Using this more accurate power level reduces the effective range of the wideband forward link to 10 miles from 20 miles.

Pinpoint's average base station separation is seven miles. Therefore only six base stations will be encompassed in the potential interference zone of 10 miles radius. Because the typical Pinpoint base station will be 200 feet above ground level (rather than the 300 feet posited by Dr. Padgett), the reduced effective range of the wideband forward link results in the noise floor being raised to -95 dBm only 5.4% of the time in a 100 kHz bandwidth throughout an 8 MHz sub-band at a receiver 30 feet above ground level.[22] At 6 feet above ground level, the Pinpoint occupancy of the 8 MHz band is down to 1%.

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[21] Metricom's analysis of AVM system interference inappropriately assumes an open area propagation environment. Under this assumption, it is worth noting that the contemplated Metricom system will raise the noise floor above -95dBm in a 100 kHz bandwidth for over 12 MHz at ground level and will raise the noise level at their own pole tops to -82 dBm over the entire 902-928 MHz band. In any event, the open area propagation environment is not typical of the urban and suburban areas where AVM systems will be deployed.

[22] The average base station does not transmit 3% of the time, as Padgett assumes. Rather, on average, an individual base station in a typical market (30-35 base stations) would initiate only about 3 percent of all position fixes. (It was in this context that Pinpoint earlier has made statements that the average duty cycle of a base station is on the order of 3%.) For a typical individual location poll, the base station transmits for around 30% of the total transaction time. Therefore, the "on-air" time of an individual base station is on the order of .9% of the total time the system has access to the spectrum.

Importantly, if Dr. Padgett applied his own analysis to Metricom's system,[23] it would reveal that Metricom transmitters operating atop utility poles would raise the average minimum noise at the receive antenna input above -90 dBm all the time over the entire 26 MHz for AVM receivers and Part 15 devices at 200 feet above ground level. In fact, the expected power at a base station receiver would be much higher than this value, for a significant part of the time, due to the large number of possible Metricom devices in the AVM bandwidth.[24] The undesired signal power into an AVM base station receiver would be -78 dBm when the receive antenna gain is considered. This is a very high level of interference generated by a device/system which its designers knew at the time it was designed and developed, could be used only if it did not cause interference to higher priority, licensed users of the band, including AVM systems.

Interference levels at antenna sites below 200 feet will be very significant as well. The noise floor will be raised at pole top level above -95dBm in a 100 kHz bandwidth for over 7 MHz (non-contiguous cumulative total) of the 26 MHz all the time. In addition the noise floor will be raised above -95dBm in a 100 kHz bandwidth at 6 feet above ground level in 1 MHz of the band (non-contiguous cumulative total) all the time. Thus, Metricom will pose a far greater interference threat than Pinpoint's ARRAY™ system.[25]

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[23] See Metricom's submittal: Response to "Further Analysis of Interference of Part 15 Devices and LMS Wideband Systems" prepared by Robert J. Zavel, Attachment 3 to the letter of Aug. 12, 1993, to the Commission by Metricom and certain members of the part 15 Coalition. The transmitter was assumed to be 30 ft. high, with +33 dBm EIRP. (Section 15.247 of the FCC's Rules allows up to +36 dBm EIRP.) Transmitter spacing, number of channels, and channel bandwidth were taken from Metricom's submittal. The Hata propagation model was used for distances greater than a mile and a two path model for distances less than a mile. Pinpoint has also been informed that the Metricom system will include some rooftop sites with potentially dozens of transceivers simultaneously active and connected to the wireline network. Thus, these sites are considerably higher in height and interference potential than the poletop transceivers. They will generate substantial noise over the entire band. These rooftop transceivers were not included in the above analysis.

[24] Some transmitters would be closer to the AVM receiver than others; the victim receiver would be jammed by the highest signal.

[25] The bandwidth occupancy is calculated using the information in Metricom's submittal and using the Hata propagation model. After adjusting for a 100 KHz bandwidth, a -95 dBm level corresponds to 2.7 miles away from the Metricom transmitter. The number of transmitters encompassed by a 2.7 mile radius is the ratio of 2.7 miles to the .5 mile spacing between transmitters, that quantity squared multiplied by PI (3.14) or 91. Since each transmitter occupies 160 KHz and is on half the time, the total bandwidth occupied by the Metricom system at an instant is 160 KHz multiplied by the 91 transmitters multiplied by the

(continued...)

Another method of illustrating the relative interference potential of Pinpoint-type and Metricom-like systems could be by comparing the total RF energy emitted in the metropolitan area. In a typical metro area an ARRAY™ AVM system must be deployed over much more than the metro area in order to provide multilateration coverage out into the fringe regions so as to provide adequate service for emergency, security and other applications. Conversely, the Metricom system is concentrated in the high-traffic areas of the metro area, i.e. their nodes would be concentrated in only certain parts of the coverage area of an AVM system like ARRAY™.

An ARRAY™ system for a typical large metro area (e.g. Dallas-Ft. Worth) would have approximately one hundred base stations. The average transaction duty cycle of any particular base station is estimated at less than 3% for a fully loaded network. However, for any given vehicle location, the actual airtime usage is only about 30% of the transaction time. For a coverage area as large as Dallas-Ft Worth, the base stations would re-use frequencies about 3 times, meaning that at any one time 3 or fewer suitably separated base stations could be active simultaneously (i.e., the network coordinates operation to prevent more being on the air simultaneously to prevent self-interference). Therefore, *assuming constant optimal frequency reuse*, the total airtime duty cycle for a fully loaded network would be 3 (reuse areas/network) x 33 (bases/reuse area) x 0.03 (transactions/base) x 0.30 (bases transmitting/transaction) = 100 (bases/network) x 0.9 (bases transmitting/base) = 0.9 (bases transmitting/network). The Dallas coverage area would be about 3500 square miles.

Conversely, the Metricom system might cover about a quarter of the AVM system's coverage area, or about one thousand square miles. At a density of four pole-top node-transceivers per square mile (according to Metricom), the system would require about 4,000 poletop transceivers. According to Metricom, 50% of all these transceivers can simultaneously be active across their 162 channels or 26 MHz, over the coverage area of a busy data network.

Therefore, the total amount of RF energy being released into the 902-928 MHz band across the respective coverage areas by the respective systems is vastly different. For the Array system it would only be about 0.9 (base transmitting/network) x 480 watts ERP/(bases transmitting) or about 423 watts ERP/network in an 8 to 12 MHz bandwidth, being spread over the 3500 sq. mile

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[25](...continued)
50% duty cycle which equals 7.32 MHz. It is noted that some transmitters as they hop might collide with others transmitters on the same frequency. This will only have a minimal effect on the total occupied bandwidth since there are 162 channels, and in order to maximize throughput, the system will presumably attempt to avoid collisions.

coverage area from base stations an average of 7 miles apart. This versus Metricom's 4000 bases/network x 0.50 bases transmitting/base x 2 watts ERP/(bases transmitting) = 4000 watts ERP/network in a 26 MHz bandwidth, spread over a 1000 sq. mile coverage area and from nodes about a half a mile apart. Therefore, the average "interference-power density" from each system would be less than 1/8 watt per square mile for the ARRAY™ system and 4 watts per square mile for the Metricom system. This is a ratio of over 32 times in favor of the ARRAY™ system causing less interference[26] to all band users.

Moreover, due to Metricom's frequency hopping design, the sections of the band experiencing the high levels of interference are non-contiguous and constantly changing. This makes it virtually impossible for any device trying to share the band to avoid Metricom's interference, in contrast to AVM system interference which is much easier to avoid. From this analysis, it is clear that if Metricom's wideband system is deployed, the entire 902-928 MHz band will be significantly degraded to the detriment of all other potential users of the band, both Part 15 and AVM. Thus, it seems that the real choice facing the Commission is not so much one of all Part 15 devices versus AVM but rather whether to allow a narrow category of unlicensed devices (actually a single, self- coordinating system rather than randomly operating unitary equipment, like cordless phones, characterized as operating outdoors at high power, high antenna elevation, and with a high transmit duty cycle) to preclude licensed services like AVM and AVI.[27]

Instead of using unlicensed spectrum in the 902-928 MHz band for such PCS-like applications, companies such as Metricom should be required to participate in the broadband PCS auctions this fall rather than congest bands which have been designated for shared use by both other Part 15 devices and higher priority licensed AVM and AVI systems.

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[26] Even if the different bandwidths are taken into account (for watts per square mile per MHz) there is still a ratio of 10:1 in favor of an 8 MHz AVM system, but this is of little help from the Part 15 interference perspective, since they cannot avoid Metricom, but they could avoid Array.

[27] While point-to-point systems can also be a problem, their adverse effects can usually be ameliorated through reconfiguring the geometry of the link or moving the center frequency of the link.

Indeed, the Pinpoint ARRAY™ System Is Compatible with a Large Number of Part 15 Devices

Not only is the Pinpoint system not the most serious source of potential interference to Part 15 devices in the 902-928 MHz band, it will be compatible with a large number of Part 15 devices used in a wide variety of applications. Pinpoint has conducted several qualitative tests on various Part 15 devices including cordless phones and consumer video relay equipment. These tests indicate that normal use of these Part 15 devices does not have a significant impact on Pinpoint's ARRAY™ system,[28] nor did the ARRAY™ system's wideband forward link render these devices inoperable.

For example, Pinpoint tested a Part 15 frequency hopping cordless phone to determine its relative performance under various interfering scenarios. In its normal operating mode, the cordless phone functioned without degradation over its full range within the building when the base unit of the phone was within 300 feet of a Pinpoint ARRAY™ base station. Only after the phone was forced to select frequencies within the same part of the 902-928 MHz sub-band as the ARRAY™ system was any degradation detected. The most severe test setup is illustrated in Figure 1. The base unit of the cordless phone was set up right next to the window so that it lay in direct line of sight to the ARRAY™ antenna sight. The handset was moved around to various locations and distances to determine the qualitative voice degradation of the link using its intercom function.

The cordless phone operated for a range of 250 feet in the building without degradation when the Pinpoint ARRAY™ base station was not operating. With the cordless phone base unit in this position and the ARRAY™ base station transmitting 7% of the time[29] at a range of about 300 feet from the phone base unit, the phone

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[28] Dr. Padgett argues that a wideband forward link is more likely to suffer interference than a narrowband forward link. While theoretically this is true, when selecting its system design, Pinpoint considered this among a number of factors such as the processing gain associated with a wider bandwidth and the minimum amount of ground level interference that the system would experience. Pinpoint also considered the statistical nature of the potentially interfering sources, which requires a congruence of spatial, temporal, and frequency considerations in order for interference to occur. See discussion of Pinpoint Reply Comments March 29, 1994, at pp. 29-30.

[29] The base station ERP was 100 W for the test rather than the expected 500W ERP in a deployed network. In order to compensate partially for this, the airtime usage was increased to 7% from the expected average of 0.9%. In addition, the test transmitter sent a

(continued...)

still operated to a range of 250 feet but with varying noticeable degradation; the degradation disappeared at a range of 50 feet from the cordless phone base station. The phone lost the link beyond 250 feet with or without the ARRAY™ transmitter on.

It is noteworthy that the test was conducted in a building and that intervening walls can greatly affect the results. For example, moving the base unit in 30 ft from the window reduced the interfering signal by 20 dB. The non-degraded range would be expected to show a corresponding increase. In general, most degradation arising from interference can be offset by rearranging the geometry of the Part 15 device (i.e. moving it around). This is not an unreasonable approach since Part 15 devices must already contend with a host of other Part 15 interferers in similar ways.[30]

It is also important to note that in order to conduct these tests, the Part 15 phone had to be fooled into staying in the channel in which Pinpoint's station transmitted. As Dr. Padgett and others have pointed out, many Part 15 devices are "smart" frequency hoppers that try to avoid interference by moving to different channels. Thus, outside the artificial "worst case" environment of the test, the Part 15 phone user would have experienced no interference if an 8 MHz AVM system had operated in the local geographic area. Accordingly, for this reason, Pinpoint recommends that, as an interference mitigation strategy, the Commission encourage Part 15 devices to be frequency agile so as to operate in at least 3 distinct sub-bands in the 902-928 MHz band.

Conversely, Pinpoint does anticipate that most Part 15 devices will not pose a harmful interference threat to its system. Indeed, based upon its testing and analysis, Pinpoint is confident that Part 15 devices operating within the following parameters will, in almost all cases, present no threat of interference to its AVM system:

1. Devices operating indoors (both transmitter and receiver within the same structure), or

2. Outdoor devices operating at or below 10 feet above ground level and

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[29](...continued)
2.7 ms burst, typical of a message containing 750 bits of user data rather than a location poll, which is only a few hundred microseconds in length. This provided a nearly worst case scenario for the test.

[30] With digital devices, the Commission requires that instruction manuals explain this simple mitigation strategy. See 47 C.F.R. 15.105(b) (1993).

a. at an EIRP below 20 dBm, or

b. at an EIRP at or above 20 dBm with on-the-air time less than 10% in any one hundred (100) second period.

Consequently, the following Part 15 devices, in effect, should be non-interferers to Pinpoint:

A. Cordless phones

B. Wireless PBXs

C. Wireless LANs

D. Wireless speakers and consumer video relay equipment

E. Restaurant pagers

F. Automatic Meter Readers such as the current Itron (EnScan) variety used by Washington Gas.

These operating parameters are very similar to the interference criteria proposed in the FCC staff's recent informal proposal. Were the Commission to adopt a rebuttable presumption of non-interference, a more appropriate balance between licensed and unlicensed devices would be criteria based on the height, power, and duty cycle limits Pinpoint outlines above. (The interference caused by devices exceeding these criteria would be presumed to be "harmful".) Under these criteria only high-power PCS-like systems would likely be presumed to cause interference.[31]

CONCLUSION

The design of a wide-area AVM system requires tradeoffs between a host of system elements: bandwidth, mobile power, base station power, density of base stations, ranging accuracy, timing uncertainty, multipath pulse separation, throughput, and so forth. These tradeoffs must be considered in concert within the context of service objectives, the environment of actual operations, and other users of the spectrum.

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[31] While field disturbance sensors would not meet these criteria, Pinpoint understands that they generally could operate within the lower 2-3 MHz of the 902-928 MHz band.

In attempting to disparage the Pinpoint system design, Dr. Padgett treats various design features such as the wideband forward link and system bandwidth in isolation. As a result, he reaches erroneous conclusions about the Pinpoint's system design. At bottom, his recommendations that no more than 4 MHz he allocated for individual wide- area AVM systems and that wideband forward links be prohibited are misguided.

Pinpoint has explained in detail that a bandwidth of at least 8 MHz, and preferably 12- 16 MHz, is needed for adequate ranging accuracy and location throughput for the high- capacity IVHS applications it intends to serve. Moreover, the use of a wideband forward link in the same spectrum as the return link is more conducive to spectrum sharing by multiple wide-area AVM operators and efficient use of the band by all users. A narrowband forward link system, in contrast, will require an additional 1.3 to 3.4 MHz of dedicated spectrum for high-powered base stations to serve the same operational objectives, in addition to the wideband link necessary for the mobile-to-base ranging pulses. Thus, a narrowband forward link serves to create additional compatibility problems.

Finally, the Pinpoint AVM system represents a far lesser interference threat to other users of the 902-928 MHz band than the Metricom Part 15 PCS-like data distribution network. Indeed, based on Pinpoint's testing and analysis, the operations of the ARRAY™ system and virtually all Part 15 devices other than Metricom-like configurations should be compatible.

Respectfully submitted,

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Attachment